Study of LIGO-South Location

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Questions:

- How is the orientation of LIGO South influenced?
- Impact of the move from Hanford to Gingin?

Studies done by PSU, Cardiff, UFL https://gwastro.psu.edu/wiki/LIGOSouth/index.php?title=Modeling

Keith Riles's page on pulsar search http://gallatin.physics.lsa.umich.edu/~keithr/cw/protected/LIGOsouth/

Wiki page for LIGO South science case https://www.lsc-group.phys.uwm.edu/twiki/bin/view/Bursts/LIGOSouthScience

and more

We consider these questions with motivation of triggered-search.

Location of LIGO South

- Geodetic (115°42′30″E, 31°21′30″S, 17.94m)
- Altitude: 51m (from http://topocoding.com/)
- Geoid height: -33.060m (from <u>http://earth-info.nga.mil/GandG/wgs84/</u> gravitymod/egm96/intpt.html)
- Directions of arms are not decided.

 We study the coverage of the antenna pattern function of detector network H1-L1-V1-S1 changing directions of the arms.



Geodetic to Earth fixed coordinate





Fraction of sky region above threshold = 0.4

Antenna pattern function is defined as

$$F_{av}(\theta,\phi) = \frac{1}{d} \sum_{d} (F_{d+}(\theta,\phi)^2 + F_{d\times}(\theta,\phi)^2)$$

fraction is defined as

$$\frac{\int \int (F_{av}(\theta,\phi) > 0.4) \sin \theta d\theta d\phi}{\int \int F_{av}(\theta,\phi) \sin \theta d\theta d\phi}$$



Triggered-search

- Follow-up of external triggered events
 - We can use sky position, time

→ How accurate can we estimate a waveform using them?

- Follow-up of GW-triggered events
 - We can give: Rough sky location, time
 - → How accurate can we localize the sky location?

Follow-up of external triggered events

Questions: (again)

- How is the orientation of LIGO South influenced?
- Impact of the move from Hanford to Gingin?

Assumption:

- The error of the sky location is within 4 degrees.
- No calibration error

Theoretical study: waveform reconstruction

Tikhonov regularized maximum likelihood approach tries to maximize L_g :

 $L_g = -[\parallel \mathbf{x}(t) - A\mathbf{h}(t) \parallel^2 + g\Omega(\theta, \phi)]$

When we know the source location, Estimation error is

$$E\{\|h_g - h\|^2\} = E\{\|h_g - E\{h_g\}\|^2\} + E\{\|E\{h_g\} - h\|^2\}$$
variance
Bias
(h_g is reconstructed h which maximizes Lg.)

variance

$$E\{\|h_g - E\{h_g\}\|^2\} = \sigma^2 \text{Tr}[(g\Omega + A^T A)^{-1} - g\sigma^2(g\Omega + A^T A)^{-2}]$$

g=0 (no regulator)

$$E\{\|h_g - E\{h_g\}\|^2\} = \sigma^2 \text{Tr}[(A^T A)^{-1}]$$

We evaluate the ratio of variance at eath (θ, φ)

$$\begin{aligned} \mathsf{SIr50 vs SIr00} \\ r(S1r50, S1r00) &:= \frac{\mathrm{Tr}[(A^TA)^{-1}](S1r50)}{\mathrm{Tr}[(A^TA)^{-1}](S1r00)} \\ \mathsf{SIr50 vs H2} \\ r(S1r50, H2) &:= \frac{\mathrm{Tr}[(A^TA)^{-1}](S1r50)}{\mathrm{Tr}[(A^TA)^{-1}](H2)} \end{aligned}$$

Variance of the error of waveform estimation: 4 det. network HILIVISIr50/HILIVISIr00



Variance of the error of waveform estimation: 4 det. network HILIVISIr50/HIH2LIVI



Variance of the error of waveform estimation: 3 det. network HILISI / HIH2LI



Variance of the error of waveform estimation: 3 det. network HILISI / HILIVI



Simulation study: waveform reconstruction

- The orientation: of the arms is set to $\Theta = 0, 50^{\circ}$
- We made simulated data of H1,L1,V1,S1 with same sensitivity curves as designed aLIGO. We injected sine Gaussinan(SG235Q9, h_{rss}=4.9e-22 [Hz^{-1/2}]) at the sky position of Sco X-1 around time where S1 is most sensitive. For reconstruction we use RIDGE, a coherent network analysis pipeline.



HILIVISIr00 vs HILIVISIr50

SIr50 makes better reconstruction of h_x than SIr00, but not so much.



https://atlasl.atlas.aei.uni-hannover.de/~kazu/LSC/AIGO/waveSIr00r50/index.html

HIH2LIVI vs HILIVISIr50

SIr50 makes better reconstruction of h_x than H2, but again, not so much.



110 trials is in https://atlas1.atlas.aei.uni-hannover.de/~kazu/LSC/AIGO/waveH2S1r50/index.html

Confirmation using condition number



cond(HILIVISI)/cond(HIH2LIVI)

cond(HILIVISIr50)/cond(HILIVISIr00)



Follow-up of GW triggered events

Question:

- Influence of the orientation of LIGO South
- Impact of the move from Hanford to Gingin
 - How error region is localized

Studies done by PSU is here

https://gwastro.psu.edu/wiki/LIGOSouth/index.php?title=Localization_Studies

Summary

- We see improvement of waveform reconstruction and position localization by LIGO South.
- LIGO South makes better waveform reconstruction at ~76% region of the sky than H2.
- The optimal orientation makes better waveform reconstruction at ~72% region of the sky than the current location.
- But still have questions: Is the improvement critical with respect of inferring physical parameters of a GW source? Is it worth for large cost?
- Regarding test of gravity theory, LIGO South is MUST.